FeXXV/XXVI line diagnostics of galaxy clusters as a calibration-independent thermometer

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1. Abstract

We propose to observe the hot relaxed nearby clusters of galaxies A2029 and A3571 in order to use their FeXXV/XXVI emission line ratio measurement for temperature determination. We aim to use this calibration-independent temperature measurement for comparison between Chandra and XMM-Newton in order to resolve the remaining cross-calibration uncertainties. This will have a great impact on cosmology via accurate cluster temperature and mass determinations.

2. Description of the proposed program

A) Scientific Rationale:

The temperature measurement of the hot gas in clusters of galaxies plays an important role in the observational cosmology. The hydrostatic equilibrium condition enables one to use the measured temperature distribution to calculate the distribution of dark and baryonic matter within a cluster volume. The masses can be used to evaluate the baryonic fraction in a single cluster and translate this into cosmological mass density parameter. By measuring temperatures and masses of many clusters one can construct the temperature functions of collapsed objects and to calibrate the mass-temperature function. This relation is widely used when fitting the cosmological models to the temperature functions.

In cluster temperatures of 10^{7-8} K the elements are highly ionised and the temperature fit is primarily driven by the continuum shape of the emitted energy spectrum. Since the exponential cut-off of bremsstrahlung in typical cluster temperatures produces most significant effect at energies above ∼5 keV, the accurate hard band calibration is of utmost importance when performing cluster temperature measurements. However, this is difficult to obtain and often some residual uncertainties remain.

Indeed, in our work on a sample of clusters of galaxies in the IACHEC collaboration we found that the temperatures of the clusters above T=3 keV obtained with the current major X-ray instruments XMM-Newton EPIC and Chandra ACIS-S disagree significantly (Nevalainen et al., 2007). Similar discrepancy has been reported before by Kotov et al. (2005). We found that reducing the thickness of HRMA hydrocarbon contamination layer from the current public 22Å to 15Å we obtained a reasonable agreement with the hard band (2–7 keV) MEKAL fits for clusters below T=7 keV. However, the temperatures of the hottest clusters are still in disagreement, by 20% in maximum (see Fig 1).

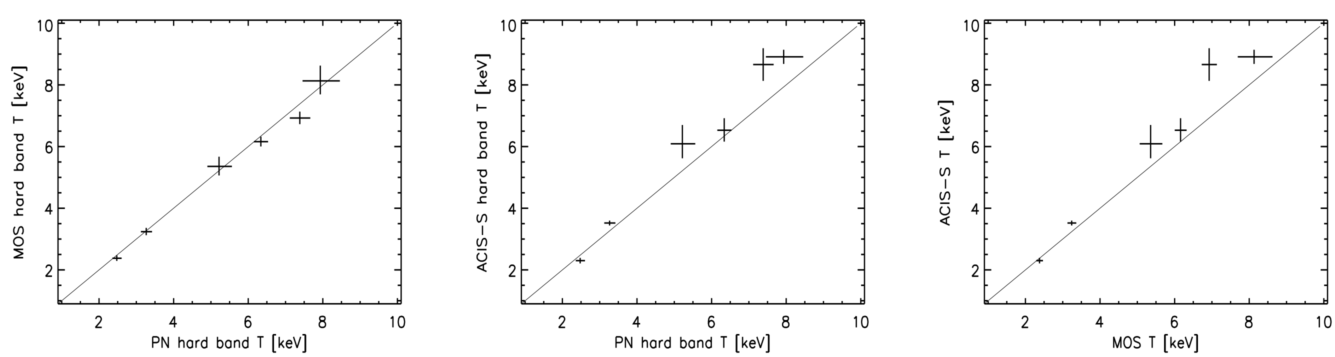

Figure 1: The best-fit single-temperatures in the 2–7 keV band for PN and MOS (*left panel*), PN and ACIS-S (*middle panel*) and MOS and ACIS-S (*right panel*) (Nevalainen et al., 2007)

Recent mass-temperature relation calibrations using XMM-Newton (Arnaud et al., 2005) and Chandra (Vikhlinin et al., 2006) disagree with the previous works based on ASCA and ROSAT (Nevalainen et al. 2000) and with the simulations of Evrard et al. (1996). It is possible that these discrepancies are due to previously unaccounted for calibration uncertainties of XMM-Newton and Chandra. Since the XMM-Chandra discrepancy is more significant in the high temperatures, the normalization and the shape of the derived mass-temperature relations using XMM-Newton and/or Chandra may have an additional systematic uncertainty not considered before. Accurate hard band calibration is thus essential in resolving the discrepancies in the M-T relation and improving the accuracy of the cosmological parameter determination by temperature function fitting.

The solution to the above EPIC - ACIS-S temperature discrepancy requires additional temperature diagnostics and we propose the FeXXV/FeXXVI line flux ratio measurement as such a tool. The proposed clusters A2029 and A3571 are among the hottest (∼8 keV) relaxed nearby clusters. At such high temperatures the FeXXVI line flux becomes significant (see Fig. 2) and measurable with the spectral resolution of XMM-Newton EPIC instruments (see Fig. 3 and Nevalainen et al., 2003). The relaxed nature of these clusters justifies the assumption that the continuum emission is of pure thermal origin, and thus enables the comparison of temperatures derived from the continuum and from the line ratio measurements. The virtue of the line ratio method is that it is nearly calibration-independent. The two lines cover a very narrow energy band (a few 100 eV, see Fig. 3) where possible calibration uncertainties have a negligible effect on the line ratio modeling. Our aim in the proposed work is to use this calibration-independence aspect of the Fe line flux ratio in order to judge whether EPIC or ACIS-S temperatures are correct. We will use this knowledge further for searching for the source of the calibration problem.

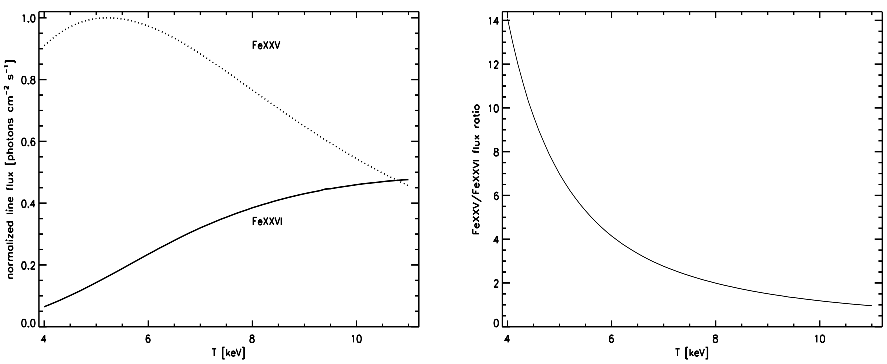

Figure 2: The fluxes of the FeXXV and FeXXVI emission lines in the MEKAL model (*left panel*) and their ratio (*right panel*) as a function of electron temperature (Nevalainen et al., 2003)

B) Immediate Objective:

We propose to re-observe hot nearby relaxed clusters of galaxies A2029 and A3571. We aim to resolve and measure the fluxes of FeXXV and FeXXVI emission lines and use this information to constrain the electron temperature in the central regions of these clusters with better than 5% statistical precision. This precision requires much longer exposures for these clusters than currently available. These results will be compared with the continuum-derived XMM-Newton EPIC and Chandra ACIS-S temperatures in order to resolve the hard band cross-calibration uncertainties.

3. Justification of requested observing time, feasibility and visibility

3.1 Filters and visibility

A search in the SIMBAD databased showed that the brightest star in the A2029 (A3571) field is fainter than 14th (9th) magnitude, and thus we propose to use a thin filter for A2029 and a medium filter for A3571.

The XMM-Newton target visibility tool indicates that A2029 and A3571 clusters are visible for a large number of revolutions in the range 1537 to 1720.

3.2 Simulations

For direct comparison with ACIS-S, we have to limit the analysis within the central $4'$ arcmin regions due to the small FOV of ACIS-S. Further limitations originate from the central cooling and the PSF scatter.

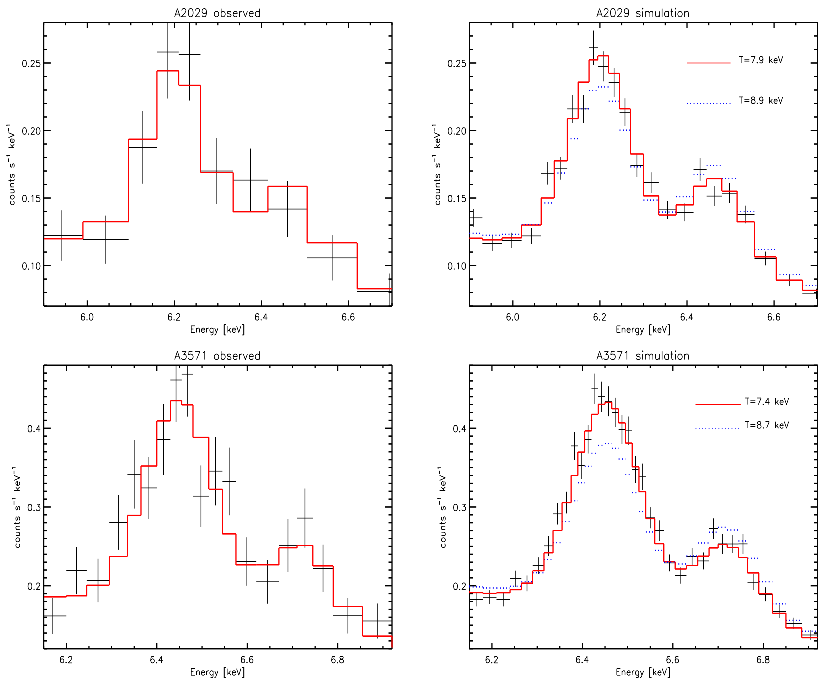

Figure 3: The observed (left panels) and simulated (right panels) XMM-Newton PN data of A2029 (upper panels) and A3571 (lower panels) together with the best-fit single-temperature MEKAL model with XMM-Newton PN value (red solid line) and ACIS-S value (blue dotted line). The simulations were done using the PN best-fit MEKAL model and exposure time of 80ks.

Considering these limitations, we have analysed annular regions of radii 1.5–2.5′ for A2029 and 0.0–2.1′ for A3571 (Nevalainen et al., 2007). The previously performed XMM-Newton observations of A2029 and A3571 (observation ID 0111270201 and 0086950201) were significantly affected by the particle flares. The effective PN exposure times, when including periods of mild flares, are 8.0 ks (A2029) and 9.8 ks (A3571). The limitations for the area and exposure time result in statistical precision of 15% (for A2029) and 6% (for A3571) for the Fe line ratio based temperature measurement (see Fig. 4).

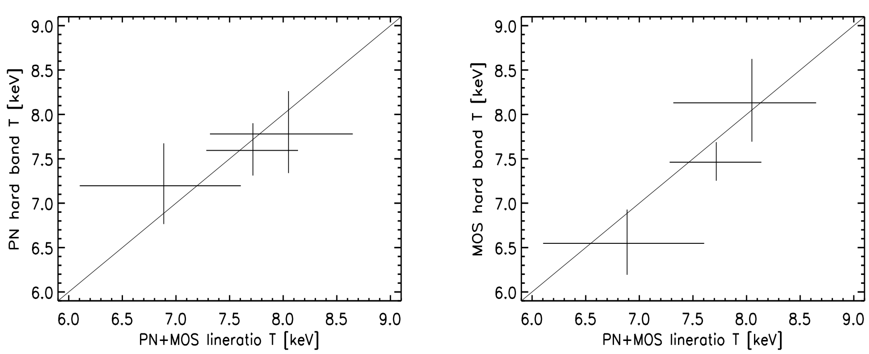

Figure 4: The Fe XXV/XXVI based temperature measurements using PN and MOS data v.s. the hard band mekal temperatures of PN (*left panel*) and MOS (*right panel*) for clusters A85, A2029 and A3571 (Nevalainen et al., 2007)

We performed XSPEC simulations is order to examine how much exposure time we need to meet our requirements for the S/N. We simulated the data for the PN instrument only. We assume that the addition of MOS data would roughly compensate for the time lost due to the flares, so that the exposure time used for PN is the actual requested exposure time.

We based the simulations on our XMM-Newton PN hard band (2–7 keV) MEKAL fits in the annular regions of radii 1.5–2.5′ for A2029 and 0.0–2.1′ for A3571. In these regions the clusters are so bright compared to the background that background effects are negligible. We fitted the data simulated with different exposure times using the same procedure as that used in the real data analysis, i.e. i) we modeled the bremsstrahlung continuum using the data in the 2–6 keV band and ii) added two Gaussian lines when including the data in the 6–7 keV band. We calculated the temperature and its 1σ statistical uncertainty using the line flux ratio measurement.

The results show that the precision of the line ratio-based temperatures increases nearly as the square root of the exposure time (see Fig.5). Based on these results, we need 80ks effective exposure time to obtain 5% statistical precision level for A2029. A3571 is more nearby and thus brighter. It does not have a cool core, and thus we can use a larger region in the analysis for A3571. Consequently, similar exposure time yields better statistical precision for A3571. Using exposure time of 80ks, we could narrow down the statistical errors to a 2% level. This level of precision enables us to distinguish between the discrepant PN and ACIS-S temperatures for A2029 (7.9 and 8.9 keV) and A3571 (7.4 and 8.7 keV) (see Fig. 3). This information allows us to judge, whether the hard band calibration of XMM-Newton EPIC or Chandra ACIS-S is more accurate. This conclusion would enable pinning down the source of the hard band calibration problem.

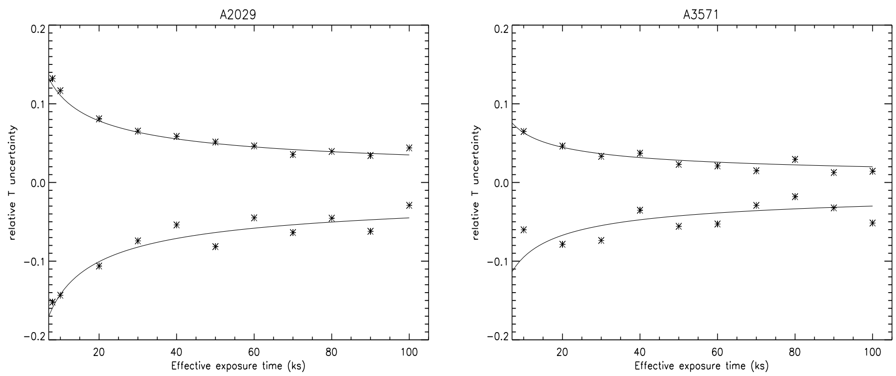

Figure 5: The relative uncertainty of the Fe line ratio-based temperature measurement as a function of exposure time for A2029 (*left panel*) and A3571 (*right panel*). The curves show the square root shape

4. Report on the last use of XMM-Newton data

The PI worked on the EPIC data on developing a background modeling method for extended sources (Nevalainen et al., 2005). The results are acknowledged by the XMM-Newton team who advertise the results on their web page (http://xmm.vilspa.esa.es/external/xmm_sw_cal/background/index.shtml).

5. Most relevant applicant's publications

Nevalainen, J., Bonamente, M., & Kaastra, J., 2007, ApJ, 656, 733: "Revisiting the Soft Excess Emission in Clusters of Galaxies Observed with XMM-Newton"

Nevalainen, J., David, L., Bonamente, M., et al., 2007, IACHEC newsletter#1: "IACHEC Standard Candles: Clusters" (http://www.iachec.org/newsletter_clusters.pdf)

Nevalainen, J., Lieu, R., Bonamente, M. & Lumb, D., 2003, ApJ, 584, 716: "Soft X-ray excess Emission in Clusters of Galaxies Observed with XMM-Newton"

Nevalainen., J., Markevitch, M. & Forman, W., 2000, ApJ, 532, 694: "The Cluster M-T Relation from Temperature Profiles Observed with ASCA and ROSAT"

Nevalainen, J., Markevitch, M. & Lumb, D., 2005, ApJ, 629, 172: "XMM-Newton EPIC Background Modeling for Extended Sources"

Other references

Arnaud, M., et al., 2005, A&A, 441, 893

Evrard. A., 1996, ApJ, 469, 494

Kotov & Vikhlinin, 2005, ApJ, 633, 781

Vikhlinin, A., et al., 2006, ApJ, 640, 691